LAWRENCE BERKELEY NATIONAL LABORATORY - UNIVERSITY OF CALIFORNIA **SPECIFICATION** **Engineering Division**			
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First Line:	US-LHC Collaboration
Second Line:	LHC IR Feedbox Specification
Title:	7.5 kA HTS Current Lead Specification

MAG

7500 A Current Leads Using High Temperature Superconductor for the LHC Inner Triplet Magnets

Rev. #	Date	Pages	Description of Change
A	13 July 00	2	Added Table of Contents
		3,4	Revised LBNL drawings, added CERN documents
		5	Clarification in 3.3, Major changes in 3.5
		6,7	Major Changes in 3.7, 3.9, and 3.10. Clarification in 3.11
		7-10	Clarification in 3.12, Major changes in 3.14 and 3.15
		11	Clarification and Minor changes in 3.16.3, 3.16.4, and 3.16.6
		12	Minor changes in 3.16.8 and 3.16.9
		13,14	Minor change and clarification in 3.18, moved 3.19 to Sec. 7, Major change in Sec 4.1, clarification in Sec. 4.2, Minor change in Sec. 5
		14-18	Major rework of Section 6, Minor changes in Section 7, Addition of Sections 8 and 9.
B	6 Aug 01	5	Delete vendor providing insulators
		8	Change mounting of Thermometers
		9	Delete Figure 3.15-1
		9	Update Figure 3.15-2
		10	Change location of V4 taps, change details of voltage tap sealing
		12	Add keystone information
		12	Change width in Figure 3.16-1

Table of Contents

1. Scope

This specification is for the design, manufacture, test, and delivery of 7500 A current leads for superconducting accelerator magnets. The superconducting magnets are inner triplet quadrupoles and dipoles that will be used at CERN in Geneva, Switzerland for the Large Hadron Collider (LHC). The hardware delivered to CERN is provided by the US-LHC Accelerator Project, which is funded by the US DOE.

The current leads will be installed by LBNL in cryogenic feedboxes, designated by CERN as DFBX. The DFBX Functional Specification is found in CERN document LHC-DFBX-ES-100.00 rev 1.0. After testing at LBNL, the completed DFBX will be shipped to CERN for installation in the LHC.

In order to minimize the heat load on the cryogenics system and thereby decrease both capital and operational costs associated with the refrigeration plant, we are requiring the bottom section of the current lead to use High Temperature Superconducting (HTS) material.

The current leads covered by this specification are similar to the 13-kA leads specified in CERN tender document IT-2441/LHC/LHC and evaluated in a major development program with worldwide industrial participation.

2. Reference Documents

The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the version used shall be the one in effect on the date of request for quotation. Any conflicts between this specification and the referenced documents shall be brought to the attention of LBNL in writing for resolution before any related action by the seller

2.1 LBNL Documents

Drawing 24C3546C, *7.5 kA HTS Current Lead*
Drawing 24C3556B, *7.5 kA HTS Current Lead Assembled*
Drawing 24C3564D, *Large Insulator Assembly*
Drawing 25I8004, *Rectangular Flange*
Drawing 24C3633A, *Sealed Receptacle Assembly*
Drawing 24C3641, *Instrument Tubing*
Drawing 24C3581, *Receptacle Back Cover*
Drawing 24C3652, *Receptacle Housing*
Drawing 24C3662A, *Receptacle Front Cover*
Drawing 24C3683A, *Reducer Assembly*
Drawing 24C3673B, *Reducer*

2.2 CERN Documents

IT-2441/LHC/LHC, "Technical Specification for the Fabrication and Supply of Prototype 13 kA Current Leads Using High Temperature Superconductor."

LHC-DFBX-ES-100.00 rev 1.0, "Functional Specification for Inner Triplet Feedboxes, DFBX" (prepared by LBNL).
LHC-PM-ES-0002.00 rev 1.1, "General Parameters for Equipment Installed in the LHC."
LHC-PM-QA-206.00 rev 1.1, "LHC Part Identification"
LHC-PM-QA-309.00 rev 1.0, "Manufacturing and Inspection of Equipment"

3. Requirements

3.1 General Configuration

The lead shall be contained in an insulated envelope of overall dimensions in conformance with LBNL drawing 24C3546C. The top end of the lead shall operate at ambient conditions of temperature from 17°C to 24°C and a dew point of 12 °C. The bottom end shall operate in a saturated bath of liquid helium, nominally at 4.5 K. LBNL drawing 24C3556B shows a typical current lead installed in the DFBX.

The upper section of the lead is a conventional gas-cooled resistive lead, cooled by a flow of gaseous helium, which enters the lead at a nominal temperature of 20 K and a pressure of 1.3 bar. A CERN-supplied valve in the LHC tunnel controls the helium flow. The flow control valve is outside the scope of this specification. The temperature sensors and voltage taps in Section 3.15 will be used to control the helium flow in the LHC.

The HTS portion is electrically connected to the lower end of the resistive section, and is cooled by boiloff vapor generated in the 4.5 K helium bath. The boiloff vapor will be returned to the CERN refrigeration system by a vent pipe at the top of the LHe chamber.

A seal, to be provided by LBNL, and shown on 24C3556B, prevents the 20 K gaseous helium coolant flow for the resistive section from entering the vapor space of the LHe chamber. The seal also provides electrical insulation. A series/parallel arrangement of Belleville spring washers maintains a design load of 10,000 lbs (45 kN) on the seal.

Two Rutherford-type cables, one of Nb-Ti superconductor and the other of pure copper strands, shall be attached to the lower end of the HTS section to provide a mechanically flexible, low resistance means of subsequent connection to the magnet bus work by LBNL. The cables are shown in Figure 3.16-1 below.

The leads will be installed in the DFBX per LBNL drawing 24C3556B. The leads are angled at 10° from vertical to allow lead removal in the confines of the LHC tunnel. Up to 3 pair of leads will be installed in a row in the DFBX. The center-to-center lead separation is 0.22 m.

The leads are operated as adjacent pairs and the polarity alternates from lead to lead. The only magnetic field acting on the current leads is generated by current flow in the leads; there is no additional background magnetic field.

The resistive section is thermally isolated by means of a vacuum jacket, and the section of current lead in the DFBX shall be electrically insulated with Kapton film or G-10CR tube.

3.2 Current Rating

The continuous current capacity of the lead shall be 7500 A. At CERN, the lead may be operated at any current between zero and 7500 A, depending on the operational mode of the LHC. The rated rate of current change, either charge or discharge, shall be 100 A/sec, between zero and 7500 A.

3.3 Voltage Rating

The lead shall withstand a test voltage of 1.5 kV dc to ground with the lead installed in the DFBX per drawing 24C3556B, where the lead will be in a helium gas environment of 1.3 bar and temperature of 300 K. The leakage current after 1 minute at 1.5 kV shall be less than 50 microamps.

3.4 Heat Load to 4.5 K Bath at Full Current

The total heat load to the 4.5 K helium bath shall be less than 0.7 W per lead at 7500 A due to joule heating in the joint and HTS material and thermal conduction while the resistive section is cooled according to Section 3.5.

The joint resistance between the HTS and LTS section shall be less than $5x10^{-9}$ ohms under normal operating conditions.

3.5 Resistive Section Cooling

At full current, the resistive section shall require no more than 0.45 g/sec per lead of gaseous helium at 20 K and 1.3 bar. The cold end of the resistive section shall be designed to maintain the warm end of the HTS section between 40 K and 50 K.

The room temperature end of the resistive section shall be designed to maintain the room temperature end above the dew point without supplemental heating at full current.

In order to provide operating headroom for the LHC, the resistive section shall not exhibit a thermal runaway if the 20 K coolant mass flow rate is decreased by 5% from the optimum value while the lead is carrying full current. The optimum value is the minimum flow rate needed to maintain the warm end at room temperature, the cold end between 45 and 50 K, and with no local temperature maximum along the length of the resistive section.

Thermal runaway is considered to exist if the reading of temperature sensor T3 in 3.15.1 exceeds 350 K after a 24-hour period.

3.6 Heat Load to 4.5 K Bath in Standby

The total heat load to the 4.5 K helium bath shall be less than 0.4 W per lead with no current while the resistive section is cooled according to Section 3.7.

3.7 Resistive Section Cooling in Standby

Under conditions of no current, the resistive section cooling shall require no more than 0.3 g/sec per lead of gaseous helium at 20 K and 1.3 bar. The warm end of the HTS section shall be between 45 K and 50 K.

3.8 Pressure Drop of Resistive Section

At full current, the helium pressure drop in the resistive section, from 20 K inlet to 300 K outlet, shall be no greater than 50 mbar at the flow rate required per Section 3.5.

3.9 Leak Rate

3.9.1 Leak Rate of Current Lead

The 20 K cooling stream of the resistive section and the 4.5 K vapor cooling stream of the HTS portion shall be separated hydraulically to prevent an unwanted heat load to the 4.5 K helium bath. The connection between the resistive section and the HTS portion shall withstand a differential test pressure of 3.4 bar without degradation. The leak rate at room temperature between the 20 K and 4.5 K sections shall be less than 1×10^{-8} torr-l-s^{-1} with a 1 bar pressure differential. Leak rate to be measured by Vendor. The LBNL-provided seal is not included in this testing.

3.9.2 Leak Rate of LBNL Separator Seal

The Vendor is not responsible for the leakage rate of the LBNL seal, other than to provide the appropriate sealing surface as defined on Drawing 24C3546C.

3.9.3 Leak Rate of the Room Temperature End

The upper extremity of the current lead, including all hardware from the mounting flange to the gaseous helium outlet port, shall have a leak rate no greater than 1×10^{-8} torr-l-s^{-1} to the environment. The LBNL-supplied test chamber which simulates the current lead installed in the DFBX shall be used to verify leak tightness.

3.10 HTS warm end Temperature

The temperature at the warm end of the HTS section shall be between 45 K and 50 K during operation at full current and in standby, as measured by the temperature sensor T1 or T2 in 3.15.1 below. Under these conditions the upper section shall be cooled with 20 K helium gas as in 3.5 or 3.7, and the HTS section shall be cooled with the helium vapor generated by the boiloff specified in 3.4 or 3.6.

3.11 HTS Temperature Margin

To ensure operating temperature margin, the HTS element must be designed to operate in a stable manner at full current with the warm end temperature maintained at 60 K. This will be verified with an increased flow of warmed inlet gas.

3.12 HTS Stability and Protection

3.12.1 Loss of Coolant

The HTS section must not quench if the current is reduced from 7500 A with a time constant of 10 sec, starting within 5 sec of loss of 20 K coolant flow and a simultaneous loss of liquid helium bath.

3.12.2 HTS Quench

In the LHC, the quench detection system will assume the HTS section has quenched when the voltage across the entire length of the HTS section exceeds the Vendor-defined threshold voltage for 5 sec. The threshold voltage shall be 100 mV or greater. After a further 1-sec delay for equipment switching, the current will be exponentially discharged with a time constant of 10 sec. The resulting ohmic heating shall not damage the HTS portion or modify the properties. The peak temperature shall remain below 200 K in this situation.

3.13 Design Pressure

The current lead, as installed in the DFBX with electrical isolators, instrumentation connectors, and terminals, shall withstand a test pressure of 4.4 bar (absolute) in the 20 K coolant circuit. This is in addition to the pressure requirements in Section 3.9. The test chamber required to simulate the lead installed in the DFBX per 24C3556B for this test will be supplied by LBNL.

3.14 Operational Goals

The 20-year operational lifetime of the current lead includes: a minimum of 25 thermal cycles between room and operating temperatures, a minimum of 12000 electrical cycles between zero and full operating current, and 15 years at full current.

3.15 Instrumentation

Each lead shall contain temperature sensors and voltage taps for interlocks, process control and protection. The circuit diagram is shown in Figure 3.15-2.

3.15.1 Temperature Sensors

Two temperature sensors, labeled T1 and T2 in Figure 3.15-2, are required to measure the warm end temperature of the HTS section. They are located in the interior of the resistive section .

The sensors T1 and T2 are Pt - RTD type, class A, with a European standard temperature coefficient (alpha) of 0.00385. The sensors shall be

Omega PR-10 or equivalent, enclosed in a 0.188 inch (4.8 mm) o.d. 304 stainless steel sheath. A four-lead configuration is required.. T1 is 30 mm long and is fixed in place with epoxy. T2 is full-length, with threads and Apiezon N ™ at the cold end.

A temperature sensor, labeled T3 in Figure 3.15-2, is required to measure the lead temperature rise with reduced flow rates. It is located in the interior of the resistive section, approximately 10% of the distance down the resistive section from the warm end to measure the temperature of the warmest portion of the lead.

The sensor T3 is a Pt - RTD type, class A, with a European standard temperature coefficient (alpha) of 0.00385. The sensor shall be Omega PR-10 or equivalent, enclosed in a 0.188 inch (4.8 mm) o.d. 304 stainless steel sheath. A four lead configuration is required. The sensor assembly shall be easily installed and removed from the warm end of the current lead. The Vendor shall incorporate a suitable spring mechanism at the warm end and Apiezon N™ thermal contact grease to maintain good thermal contact at the measuring end of the sensor.

The temperature sensor lead wires shall be connected to a feedthrough as shown on Figure 3.15-2. The sensors shall withstand a voltage of 300 V DC with respect to the current lead. During the high voltage testing in Section 3.3 the temperature sensors and their lead wires shall be at the same potential as the current lead.

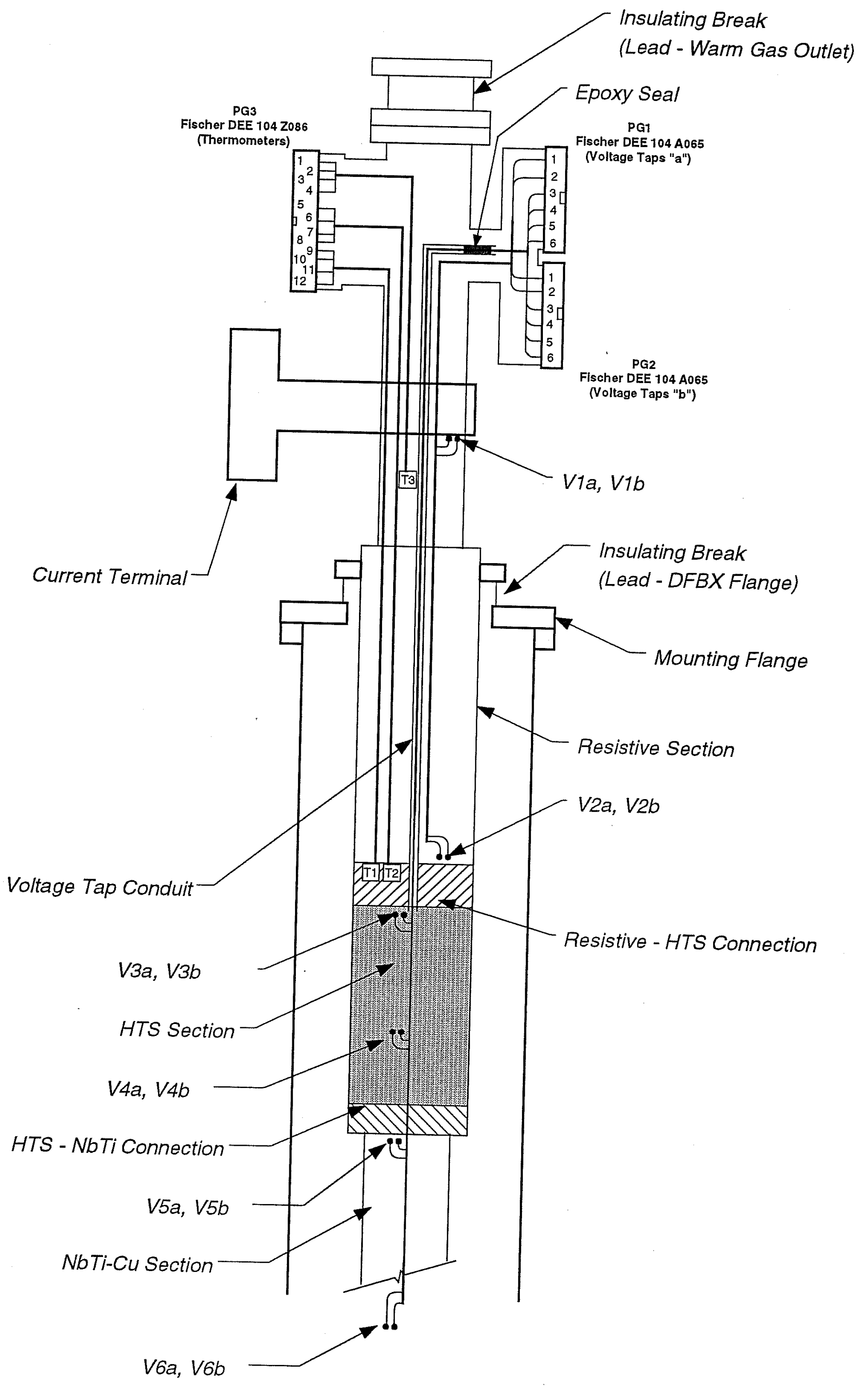

Figure 3.15-2. Instrumentation Schematic

3.15.2 Voltage Taps

The Vendor shall attach voltage taps at the locations shown on LBNL drawing 24C3546C and indicated on Figure 3.15-2. For redundancy, two independent taps are required at each of the seven locations:

- V1a and V1b are on the warm end of resistive section,
- V2a and V2b are on the cold end of the resistive section,
- V3a and V3b are on the warm end of the HTS section,
- V4a and V4b are on the midpoint of the HTS section
- V5a and V5b are on the near end of the LTS section, and
- V6a and V6b extend 4 meter beyond the lead for future LBNL usage.

The voltage taps shall be routed through the interior of the current lead as indicated on Figure 3.15-2. To maintain the leak-tightness requirement of 3.9.1, the voltage tap wires for V3, V4, V5, and V6 shall pass through a hermetic feedthrough at the cold end The voltage taps V1 and V2 are routed separately through the resistive section. It is desireable to route all voltage taps as closely as possible to the center of the current lead.

3.15.3 Electrical Signal Connectors

The twelve (12) temperature sensor lead wires shall be on a connector separate from the voltage taps. The connector for the temperature sensors (PG3 in Figure 3.15-2) shall be W.W. Fischer Model DEE 104 Z086. The Vendor shall perform all electrical connections.

The connectors for the voltage tap wires sensors (PG1 and PG2 in Figure 3.15-2) shall be W.W. Fischer Model DEE 104 A065. The Vendor shall perform all electrical connections.

The connector housing is shown on LBNL Drawing 24C3633A, with details given on the referenced drawings.

3.15.4 Signal Connector Location

The preferred locations and configurations for the signal connector housings are shown on LBNL drawing 24C3546C. The Vendor shall ensure sufficient thermal isolation from the cold sections of the lead to prevent condensation or ice formation on the connectors.

3.16 Physical Constraints

3.16.1 Overall Length

The overall length of the lead, measured from the bottom of the HTS section to the top of the GHe outlet port, shall be no greater than 1450 mm.

3.16.2 Gaseous Helium Outlet Port

The gaseous helium (GHe) outlet port shall be a ConFlat™-type flange, non-rotatable, 2 ¾ inch (69.85 mm) diameter, with clearance holes for the mounting bolts. The Vendor shall provide M6 metric stainless steel fasteners.

3.16.3 Current Terminal

The current terminal shall be fabricated from CDA 101 (OFE) or ETP-type copper and exposed surfaces plated with a suitable material such as silver or nickel to prevent oxidation of the connection surfaces. The dimensions, orientation, and position of the terminal are shown on LBNL drawing 24C3546C.

The Vendor shall provide a single M3 tapped hole to allow attachment of a voltage tap on the terminal.

3.16.4 Room Temperature Mounting Flange

The room temperature mounting flange shall be a rectangular flange with a Conflat™ -compatible sealing surface per LBNL Drawing 25I8004. The Vendor shall provide M8 metric stainless steel fasteners for attachment to the DFBX flange.

The room temperature mounting flange is required to be at ground potential during the voltage testing in section 3.3.

3.16.5 Length of Lead Inside the DFBX

The length of the lead inside the DFBX, measured from the bottom of the room temperature flange in 3.16.4 to the bottom of the HTS section shall be 1005± 2 mm.

3.16.6 Resistive Section Cooling Gas Inlet

The inlet for the 20 K gas needed to cool the resistive section shall be a single opening located 513±1 mm below the bottom of the room temperature flange in 3.16.4. The inlet shall have female pipe threads to allow for pressure testing connections to perform the tests required in section 3.9. The inlet shall be aligned parallel to Datum C on Drawing 24C3546C.

3.16.7 Connection to Nb-Ti and Copper Cables

The LBNL-supplied Nb-Ti and copper cables for connection to the HTS section are shown in Figure 3.16-1. The individual cables have a keystone angle of 1.079 ± .05 degrees.The Vendor shall ensure a minimum 50-mm-long electrical connection between the HTS section and every strand in the cables. It is acceptable to uncable a short section of the cables to ensure a good connection to the lead.

The Vendor-made electrical connection to LBNL-supplied Nb-Ti cable shall have a clamp or other mechanical means to protect the Vendor-made connection between the HTS material and the Nb-Ti cable from degradation due to inadvertent mechanical forces and heating at installation. The normal to the wide face of the cable shall be aligned parallel to Datum C on Drawing 24C3546C.

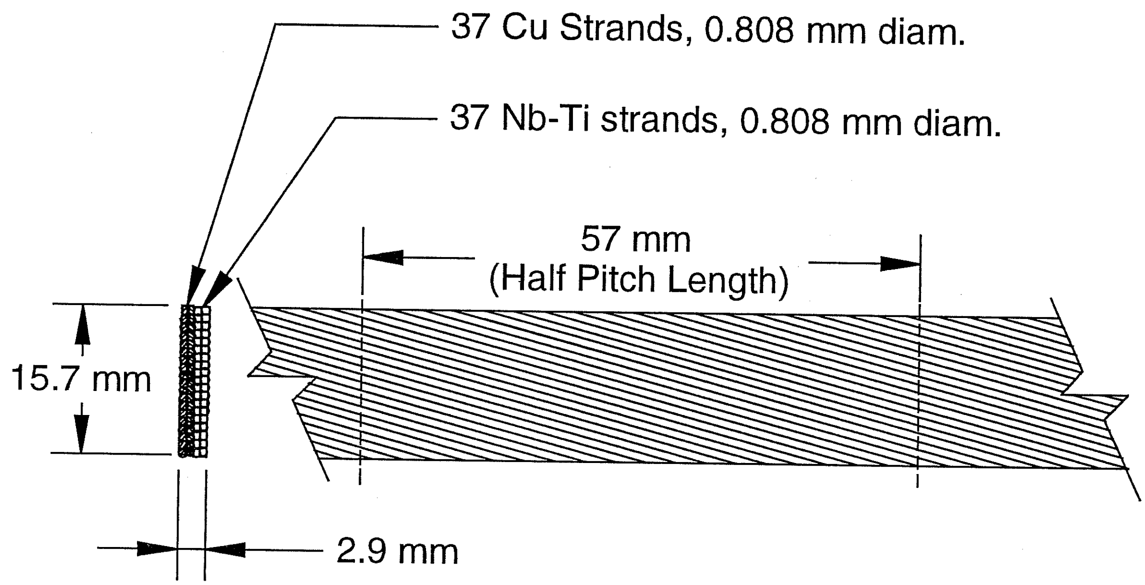

Figure 3.16-1 Nb-Ti/Cu Cable from HTS Lead

3.16.8 Connection to DFBX Bus Bars

The bottom of the HTS section of the current lead will be subjected to a mechanical force when the final electrical connections are made between the DFBX bus bar and the Vendor-supplied cables.

Vendor shall ensure that no degradation occurs under a horizontal force of 5 lbf (22 N), applied in any direction by the LTS cables at the bottom of the HTS section.

3.16.9 Connection to Warm Terminals

The ambient end of the current lead may be subjected to a mechanical force when the final connections are made to the CERN water cooled DC power cables.

Vendor shall ensure that no degradation occurs under a horizontal force of 175 lbf (750 N), applied in any direction at the center point of the warm terminals.

3.17 Maintainability

3.17.1 Signal Connectors

The Vendor shall allow 200-mm slack in the instrumentation wires to allow the signal connectors to be removed and replaced.

3.17.2 Lead Installation and Removal

To facilitate installation and removal of the Lead into the DFBX, the Vendor shall supply a suitable lifting fixture which suspends the lead from the warm terminal and/or GHe outlet port at 10° from vertical as shown on LBNL drawing 24C3556B.

3.18 Heater

The Current Lead shall be equipped with a 500 W thermostatically controlled electric heater to prevent condensation and frost from forming on the room temperature sections of the Current Lead when the Lead is in standby (zero current) or when operated at reduced currents. Heater voltage shall allow operation from 230 V, 50 or 60 Hz single-phase power source. Electrical insulation between Heater and Current Lead to satisfy section 3.3 shall be provided. During the high-pot tests, the heater will be held at ground potential.

4. Materials of Construction

4.1 HTS Material

The HTS material shall be BSCCO multifilamentary tape encapsulated in a suitable Ag-alloy matrix. The supplier of the HTS tape shall have supplied material that was incorporated into a satisfactory current lead in the CERN HTS lead development program.

The Vendor shall ensure that the tape is made according to a recognized quality control procedure such as ISO 9002. The Vendor shall ensure that all tape used in constructing the leads is sound and has a measured critical current uniform within a band of ±15% of the average value. Critical current measurements are to be taken at 77 K with no externally applied magnetic field.

The Vendor shall ensure that representative samples are taken from each end and the middle of each production length. These samples shall exhibit no measurable degradation in critical current (77K, self field) after 30 thermal cycles going from room temperature to 77 K and back to room temperature by immersion in liquid nitrogen.

Note: The Vendor is advised to ensure solderability of the tape prior to acceptance of the HTS material.

4.2 Resistive Section

Conventional resistive current lead materials such as CDA 101 or ETP-type copper, 304L or 316L stainless steel, brass, Ag braze, and 60/40 or 50/50 Pb-Sn solder shall be used to fabricate the resistive section of the lead. For other materials, LBNL approval must be obtained.

4.3 Insulation Materials

Insulation materials that are suitable for use in the current leads include Kapton, Vespel, PEEK, G-10CR, and G-11CR. Teflon shall not be used. For other materials, LBNL approval must be obtained.

5. Marking

The following information shall be stamped on the current terminal of each lead in block letters at least ¼ inch (6.4 mm) high. See LBNL drawing 24C3546B for the desired location.

Lead Current Rating (A)
LBNL Specification Number
Vendor Name
CERN Part Number
Date of Manufacture
Country of Manufacture

The CERN Part number will be specified by LBNL.

6. Quality Assurance

6.1 General

Vendor shall have and utilize a general, company-wide quality assurance plan adapted as required for this fabrication. The Plan shall address design, material procurement, fabrication, process control, process-testing, and final testing. The plan shall be in compliance with LHC-PM-QA-309.00 rev 1.0, "Manufacturing and Inspection of Equipment".

6.2 Engineering Design Review

Before authorizing fabrication of the first lead pair, LBNL will conduct a review of the Vendor-proposed current lead design to ensure that the requirements of this specification are met. The review will be held at the Vendor site and will cover:

- Design drawings (layout and detail)
- Engineering Analysis
- R&D Test Results
- Operational Parameters
  - 20 K flow rate
  - Voltage drop across resistive section
  - HTS Quench Detection Voltage
- QA Plan (including proposed traveler)

- Proposed Material Specifications and Certifications
- Production Plan (in draft form, including subcontractors)
- In-Process Test and Inspection Plan (in draft form)

After the deficiencies discovered in this review are corrected to LBNL's satisfaction, LBNL will authorize the fabrication of the first lead pair (the first article).

6.3 Vendor Inspection and Testing of First Article

The Vendor is responsible for carrying out the inspection and testing required by the Quality Plan in 6.1, and as approved by LBNL at the Engineering Design Review in 6.2. LBNL technical representatives reserve the right to witness inspections and tests at the Vendor or Subcontractor facilities.

As a minimum, the Vendor Tests on the completed First Article shall include, but not be limited to:

Conformity to dimensions on the mechanical drawings
Perpendicularity of lead body with respect to the mounting flange
Position of the separator seal surface
Flatness, perpendicularity, and surface finish of the separator seal surface
Overall Length
Position of 20 K Cooling Inlet w.r.t. mounting flange
Orientation of warm terminal
Orientation of mounting flange
Position of LTS-HTS Connection w.r.t. mounting flange
Orientation of LTS bus bar
Pressure Testing with GN_2 using LBNL-supplied chamber and seal (Sec. 3.9)
Leak checking with GHe (Sec. 3.9)
Voltage Testing using LBNL-supplied chamber and seal (Sec. 3.3)
Instrumentation Checks (Sec. 3.15)

6.4 Vendor Inspection and Test Reports of First Article

The Vendor shall compile the inspection and test reports carried out in 6.2 and 6.3 into a traveler and deliver to LBNL with the completed first article to document that the current leads were manufactured according to the approved plan.

6.5 Testing by LBNL of First Article

LBNL intends to test the first article purchased under this Specification for compliance with this specification. The testing will most probably be done using the testing facility at CERN. Testing results will be made available to the Vendor. In the event that non-conformance is determined in this testing, the Vendor will be required to make the necessary repairs or provide replacement articles to meet the requirements of this Specification. The Vendor will be invited to witness the testing.

As a minimum, the tests will consist of:
Repeat of Vendor tests in 6.3

Heat Load to 4.5 K bath in standby – (Sec. 3.6)
Resistive section cooling flow rate in standby – (Sec. 3.7)
HTS warm end temperature in standby – (Sec. 3.10)
Warm terminal heater power in standby – (Sec. 3.18)
Heat Load to 4.5 K bath at 7500 A – (Sec. 3.4)
HTS-LTS Joint Resistance at 7500 A – (Sec. 3.4)
Resistive section cooling flow rate at 7500 A – (Sec. 3.5)
HTS warm end temperature at 7500 A – (Sec. 3.10)
Warm terminal heater power at 7500 A – (Sec. 3.5)
Pressure drop in 20 K cooling circuit – (Sec. 3.8)
Resistive section temperature at decreased flow rates - (Sec. 3.5)
Measure HTS temperature margin – (Sec. 3.11)
Verify quench detection threshold voltage – (Sec. 3.12.2)
Loss of coolant tests – (Sec. 3.12.1.)

The first article must be in compliance with this specification before the Production Readiness Review will be held.

6.6 Production Readiness Review

Before authorizing fabrication of the remaining current leads (series production), LBNL will conduct a review of the modifications to the design and fabrication based on the First Article design, production, and testing results. The review will be held at the Vendor site and will cover:

- Engineering Analysis of First Article test results
- Design drawings to be used in production
- Finalized Operational Parameters
- Finalized QA Plan
- Finalized Material Specifications and Certifications
- Finalized Production Plan
- Finalized In-Process Test and Inspection Plan

After the deficiencies (if any) are corrected to LBNL's satisfaction, LBNL will authorize the fabrication of the series production current leads.

6.7 Vendor Inspection and Testing of Production Current Leads

The Vendor is responsible for carrying out the inspection and testing required by the Quality Plan in 6.1, and as amended and approved by LBNL at the Production Readiness Review in 6.6. LBNL technical representatives reserve the right to witness inspections and tests at the Vendor or Subcontractor facilities.

As a minimum, the Vendor Tests on the completed production current leads shall include, but not be limited to:

Conformity to dimensions on the mechanical drawings
Perpendicularity of lead body with respect to the mounting flange
Position of the separator seal surface
Flatness, perpendicularity and surface finish of the separator seal surface
Overall Length

Position of 20 K Cooling Inlet w.r.t. mounting flange
Orientation of warm terminal
Orientation of mounting flange
Position of LTS-HTS Connection w.r.t. mounting flange
Orientation of LTS bus bar

Pressure Testing with GN_2 using LBNL-supplied chamber and seal (Sec. 3.9)
Leak checking with GHe (Sec. 3.9)
Voltage Testing using LBNL-supplied chamber (Sec. 3.3)
Instrumentation Checks (Sec. 3.15)

6.8 Vendor Inspection and Test Reports of Production Current Leads

The Vendor shall compile the inspection and test reports carried out in 6.6 and 6.7 into a traveler and deliver to LBNL with each current lead to document that the current lead was manufactured according to the approved plan.

6.9 Testing by LBNL of Series Production Current Leads

6.9.1 Spot Testing

LBNL intends to spot-test the current leads purchased under this Specification for compliance with this specification. The spot testing may be done at both CERN and LBNL. The Vendor will be invited to witness the spot testing. In the event that non-compliance is measured in this testing, the Vendor will be required to make the necessary repairs or provide replacement articles to meet the requirements of this Specification.

A list of the measurements to be performed in the spot tests may include:

Repeat of Vendor tests in 6.7
Heat Load to 4.5 K bath in standby – (Sec. 3.6)
Resistive section cooling flow rate in standby – (Sec. 3.7)
HTS warm end temperature in standby – (Sec. 3.10)
Warm terminal heater power in standby – (Sec. 3.18)
Heat Load to 4.5 K bath at 7500 A – (Sec. 3.4)
HTS-LTS Joint Resistance at 7500 A – (Sec. 3.4)
Resistive section cooling flow rate at 7500 A – (Sec. 3.5)
HTS warm end temperature at 7500 A – (Sec. 3.10)
Warm terminal heater power at 7500 A – (Sec. 3.5)
Pressure drop in 20 K cooling circuit – (Sec. 3.8)
Resistive section temperature at decreased flow rates - (Sec. 3.5)
Measure HTS temperature margin – (Sec. 3.11)
Verify quench detection threshold voltage – (Sec. 3.12.2)
Loss of coolant tests – (Sec. 3.12.1.)

6.9.2 Final Testing

LBNL plans to test every DFBX before it is shipped to CERN, including a portion of the tests in 6.9.1. If deficiencies are discovered in the HTS leads during these tests, the Vendor will be required to make the necessary corrections, repairs, or replacements to bring all HTS leads in compliance with this specification.

7. Shipment

7.1 Delivery to LBNL

Shipment of the HTS leads to LBNL is the responsibility of the Vendor.

The current leads shall be wrapped in a weather-tight plastic film to prevent moisture and other contaminants from degrading the lead performance. The lead shall be mounted in a rugged container with shock absorbing mountings or packaging to prevent damage due to shipping loads. Vendor shall attach shock indicators to the leads to indicate if the leads were subjected to excessive shock loading during shipment.

As a maximum, two leads shall be packaged within a single container.

The test and inspection reports (travelers) defined in Sections 6.2 and 6.6 shall be shipped with each lead. The CERN part number shall appear on the reports to allow correlation of traveler to the corresponding lead.

The container shall be clearly marked with the CERN Part numbers of the leads contained within.

7.2 DFBX Shipment to CERN

The completed DFBX will be shipped to CERN following final testing of the current leads and cryogenic piping at LBNL. Drawing 24C3556B shows the lead as installed in the DFBX. In order to ensure safe delivery to CERN, the HTS Lead Vendor shall ensure that the current lead is sufficiently rugged to withstand a 2 g vertical and a 1 g transverse shipping load.

8. LBNL-Furnished Equipment and Materials

LBNL shall furnish the following equipment and materials in the execution of this specification:

Low Temperature Superconductor Bus Bar

Test chamber and seal to simulate the lead installation in the DFBX

9. Drawings

The Vendor shall furnish one set of final drawings approved in Sec.6.6 to LBNL in one of the following electronic formats: .hpgl, .dxf, or .dwg. These will be archived at LBNL and CERN for reference and use in making repairs as required. The drawings shall be provided prior to commencement of series production.